2nd Workshop Energy for Sustainable Science at Research Infrastructures

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Superconducting Links for the LHC machine

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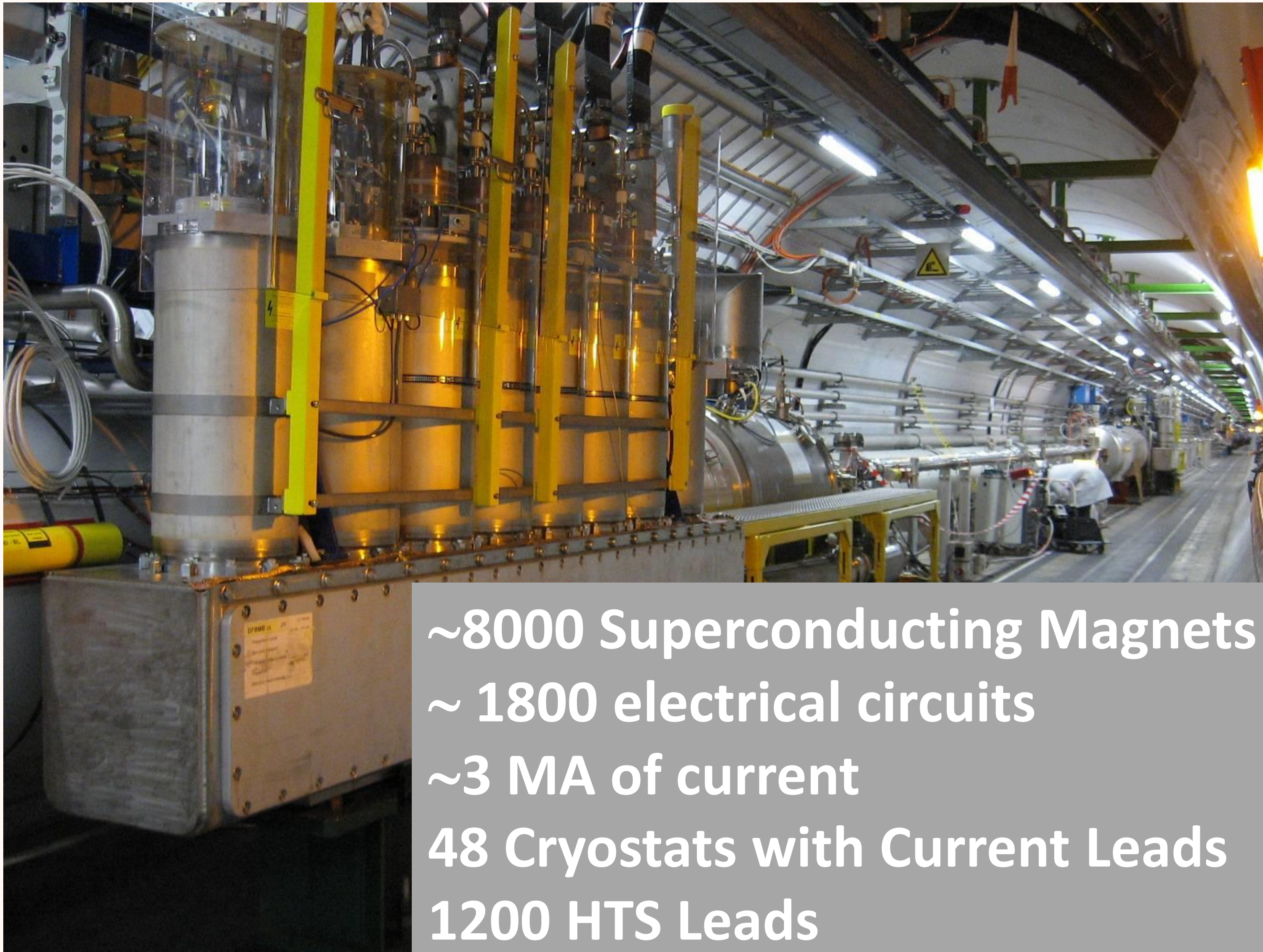
Outline

- **Energy saving in a superconducting system: electrical transfer**

- **Superconducting Links for the LHC: project overview**
  - Motivations, application to the LHC Upgrades
  - Development of superconducting lines at CERN
  - Project timeline and milestones
  - Potential applications other than LHC

- **Conclusions**

Electrical transfer in LHC



~8000 Superconducting Magnets

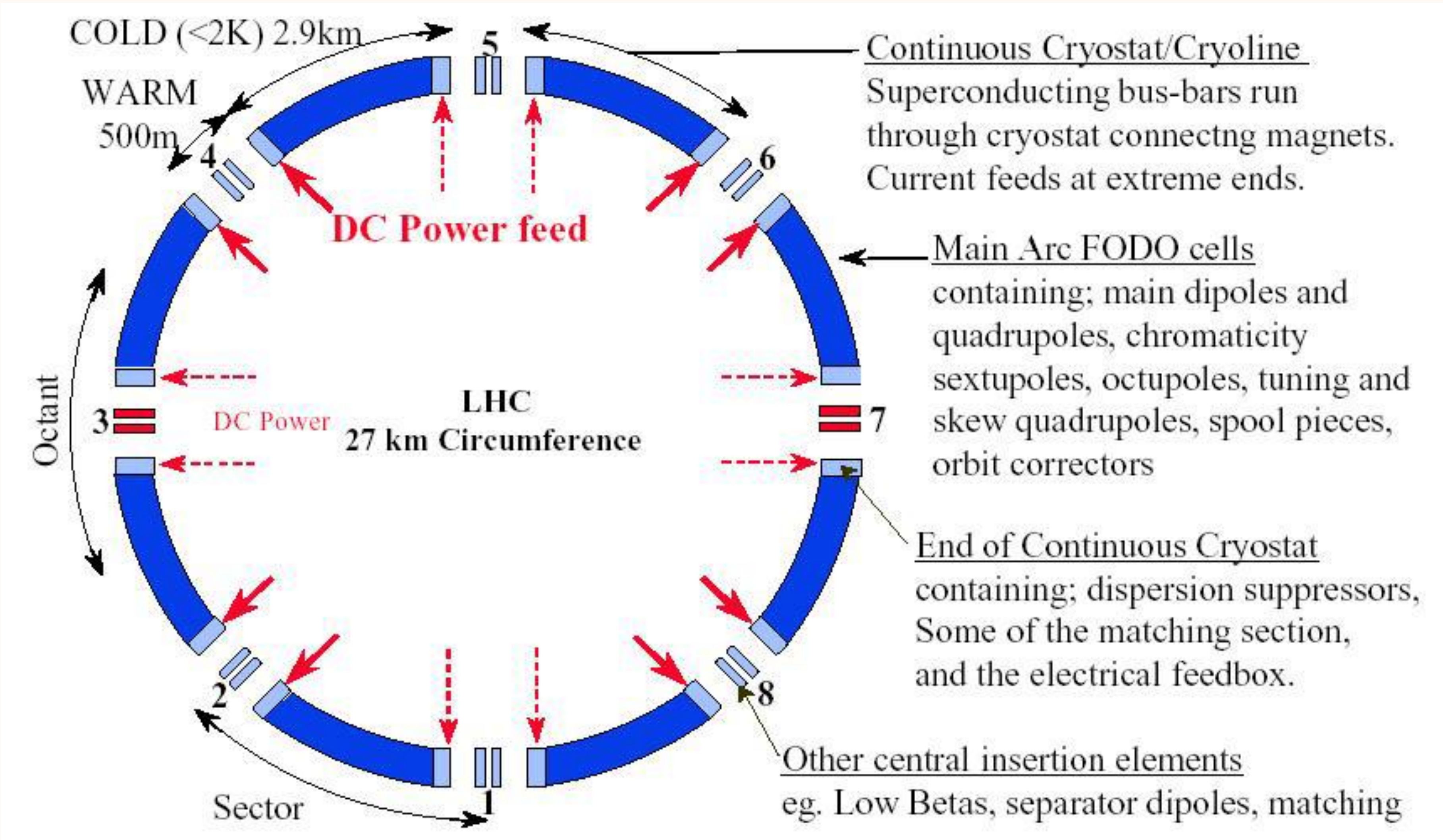
~ 1800 electrical circuits

~3 MA of current

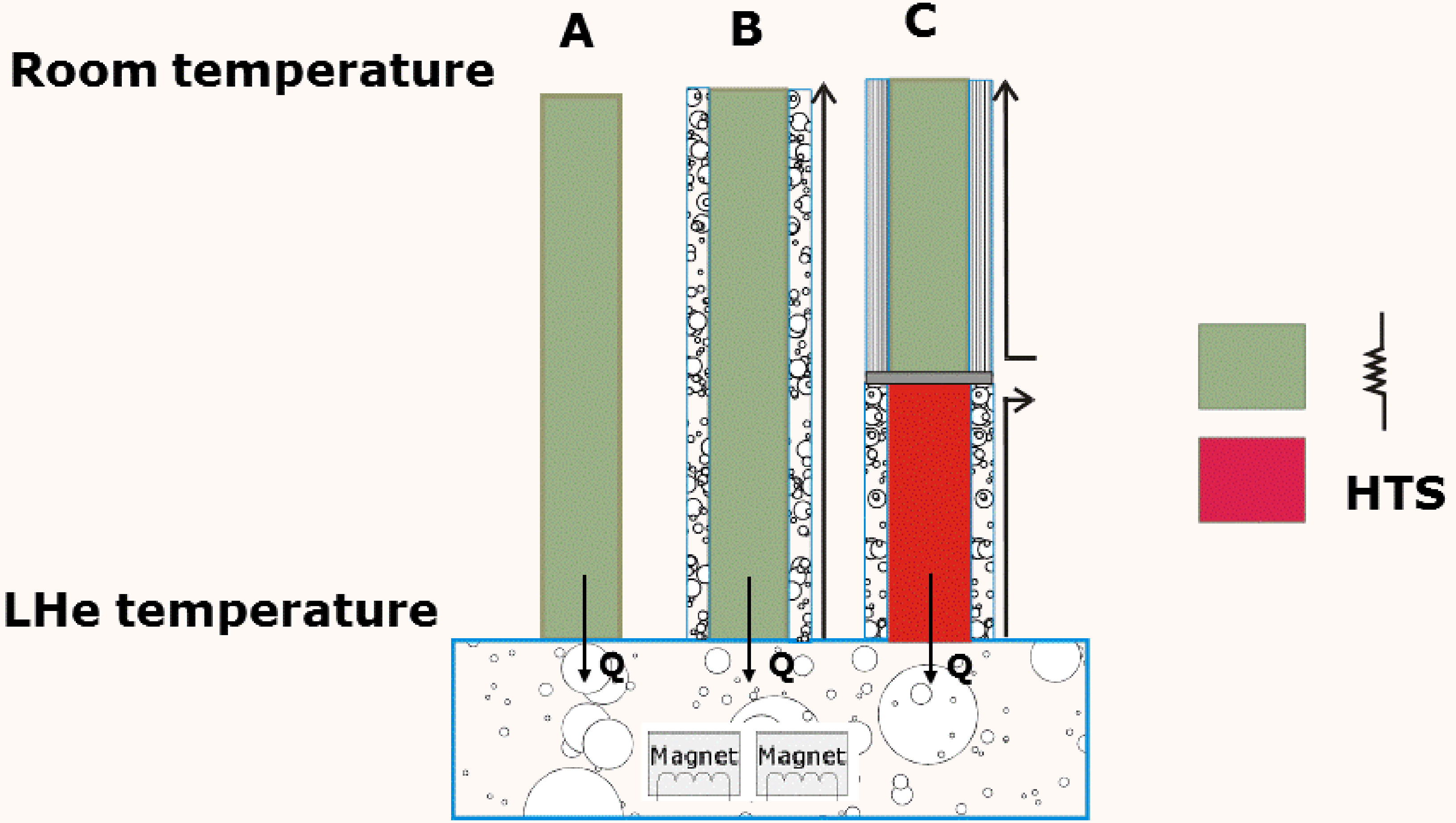
48 Cryostats with Current Leads

1200 HTS Leads

LHC Powering Layout



HTS Current Leads



QA = 47 W/kA

QB = 1.04 W/kA

QC = 0.1 W/kA

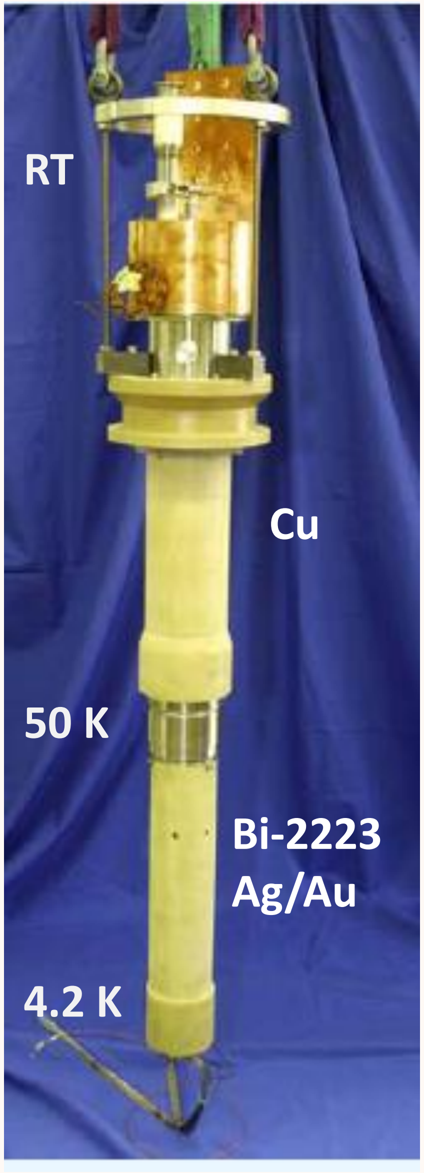
LHC: 3 MA

HTS Current Leads in LHC

3 MA of current

HTS Current Leads for circuits rated at 600 A, 6000 A and 13000 A

	Conventional leads	HTS leads
Heat load into LHe	1.1 W/kA	0.1 W/kA
Exergy consumption	430 W/kA	150 W/kA
Exergy consumption (% conv. lead)	100	35
Total exergetic power	1290 kW	450 kW
Total saving for LHC cryogenics (%)	-	~ 10



Superconducting Links for LHC

Use of Superconducting Links:

Remote powering of LHC superconducting magnets

Removal of current leads and **power converters** to easily accessible radiation-free areas

Superconducting Links for LHC

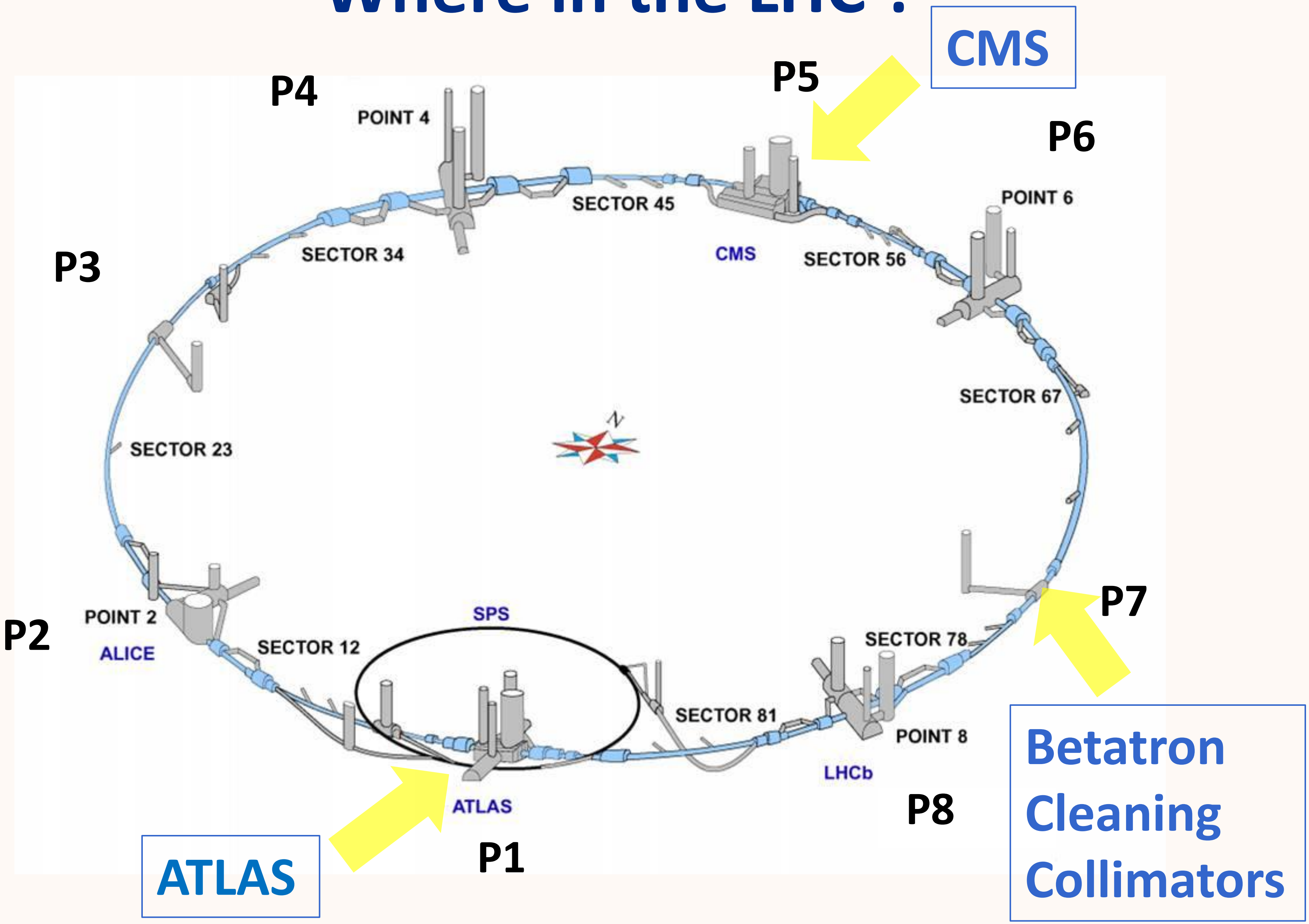
- Provide a solution that enables **removal of the LHC power converters** from radiation areas.
  Problem: SEEs and associated failure of equipment during machine operation

- **Simplify access** to tunnel for maintenance and routine operations (power converters, leads, cryogenic control equipment,…). Reduce time of interventions

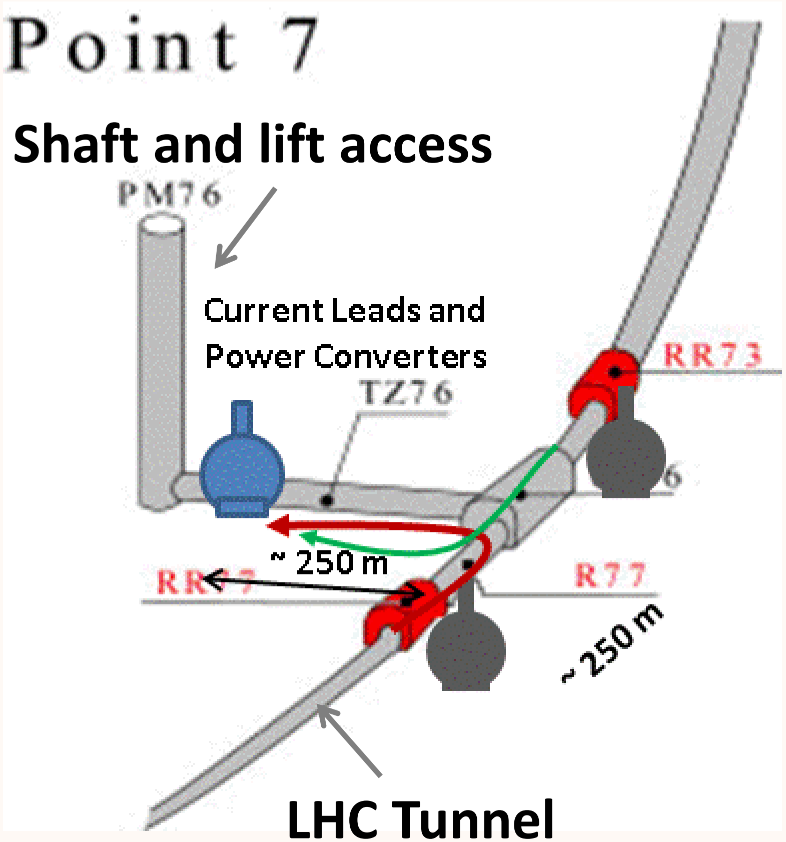
- Reinforce **ALARA** principle (minimize dose to personnel, **A**s **L**ow **A**s **R**easonable **A**chievable) by enabling maintenance and repair activities in radiation-free areas

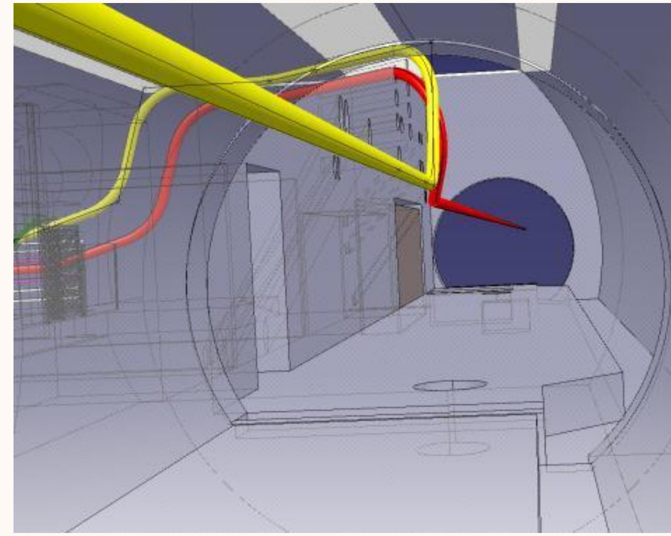
- **To free space** in the tunnel area for other equipment

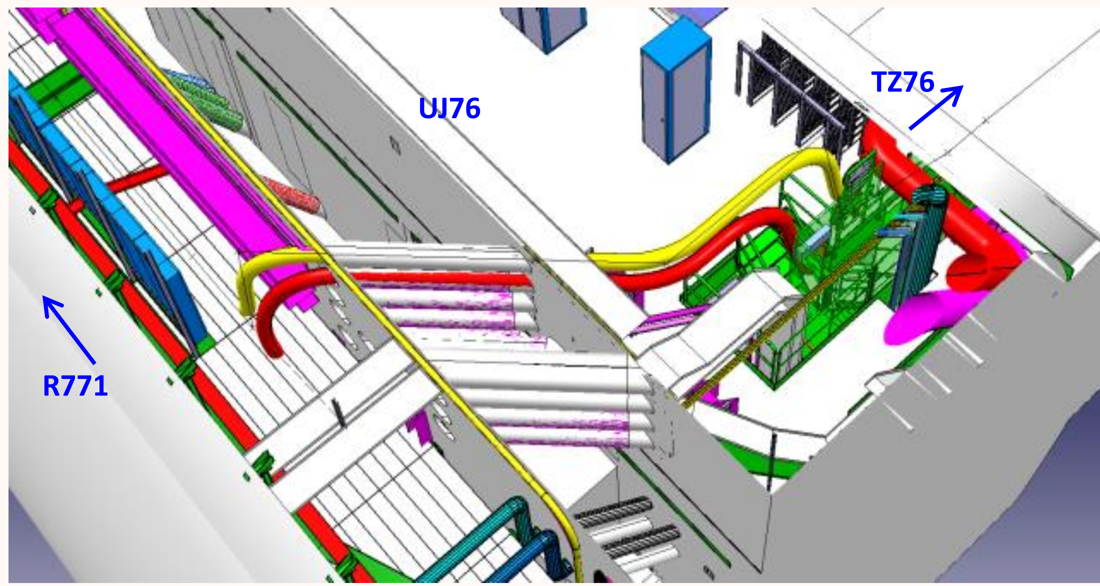
Where in the LHC ?



LHC P7



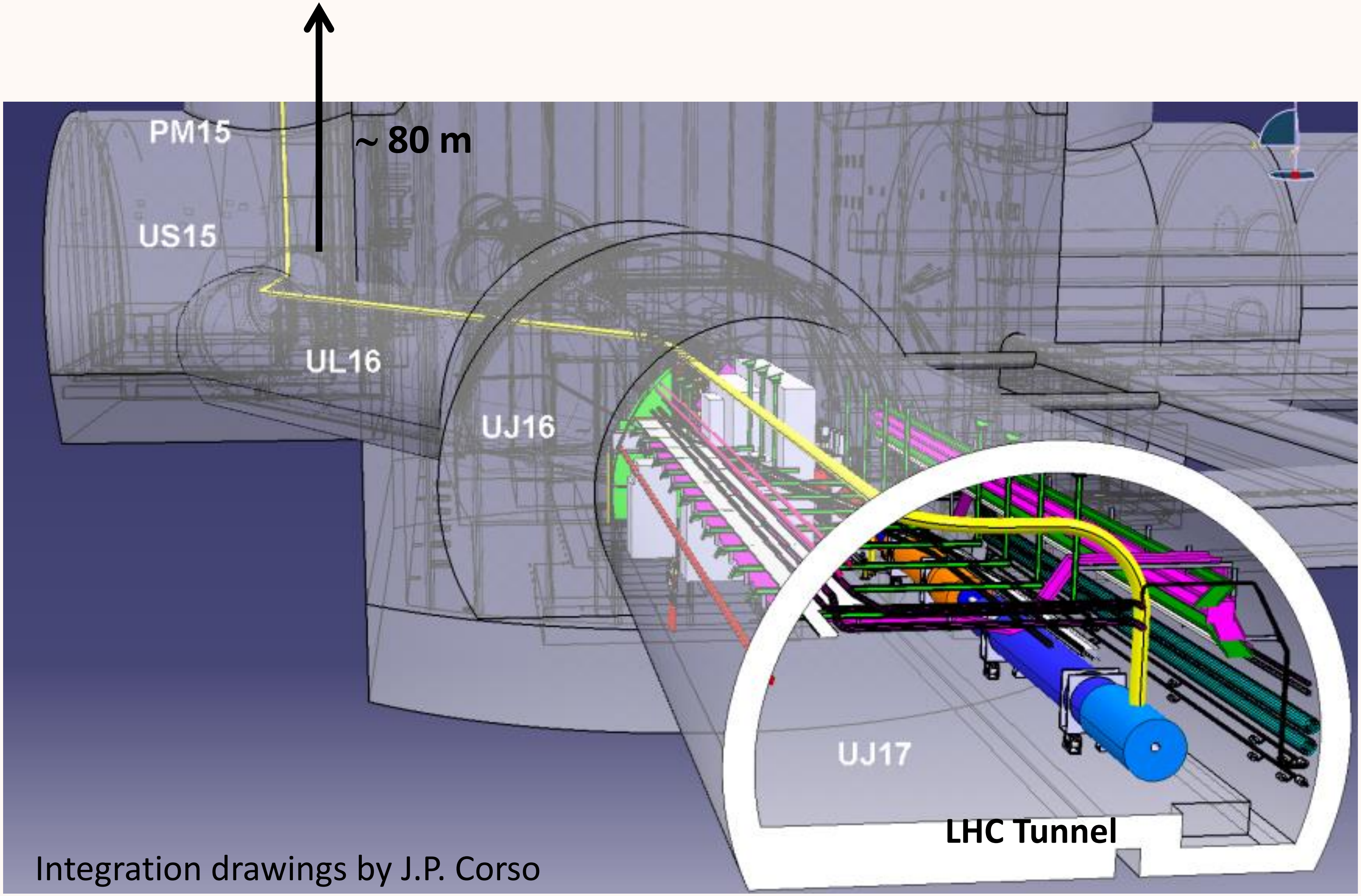




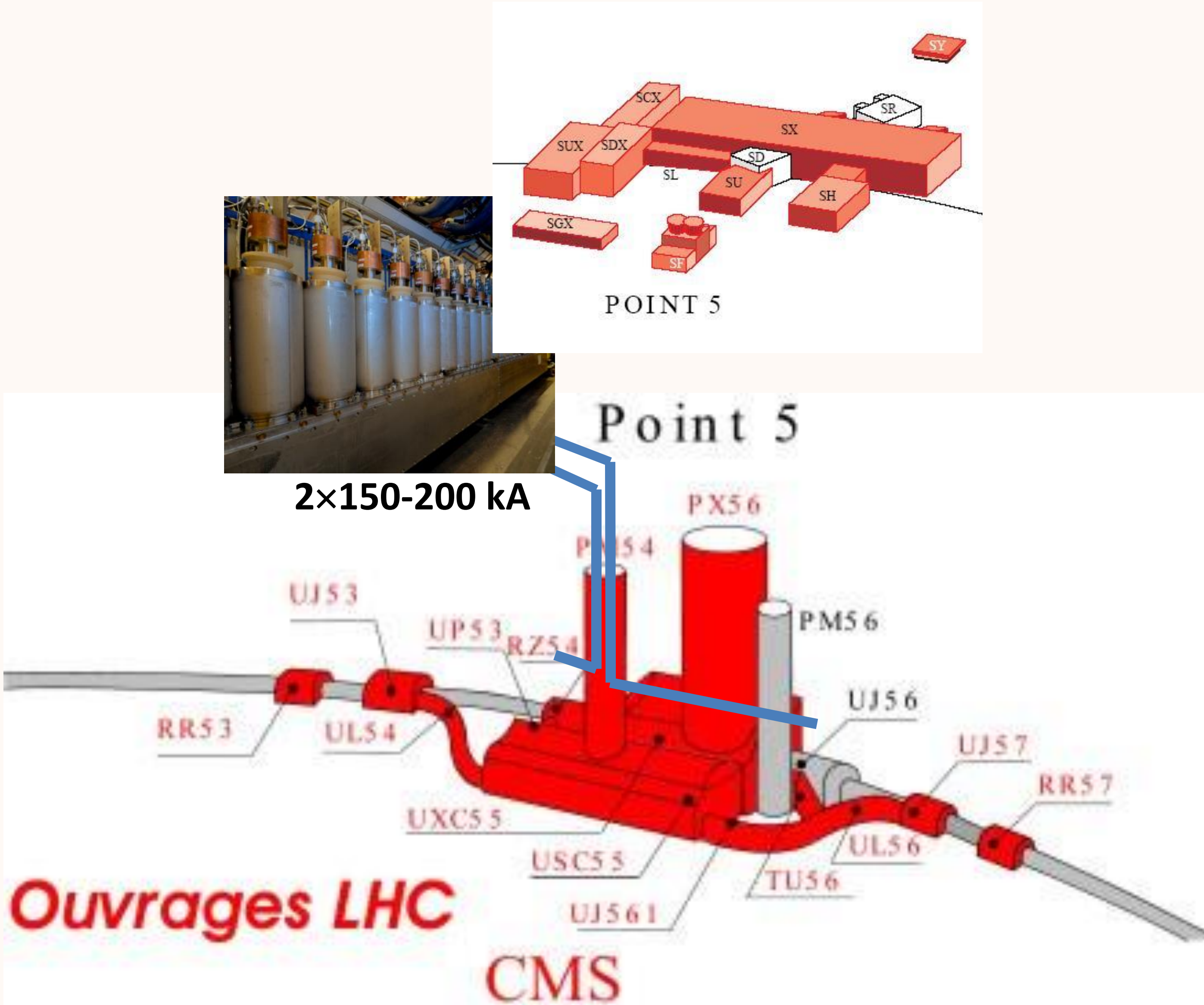
LHC P7: Cleaning Insertions

Underground Installation

Superconducting Link at LHC P1



LHC P5: Surface and Underground areas



Superconducting Links Characteristics

LHC P7

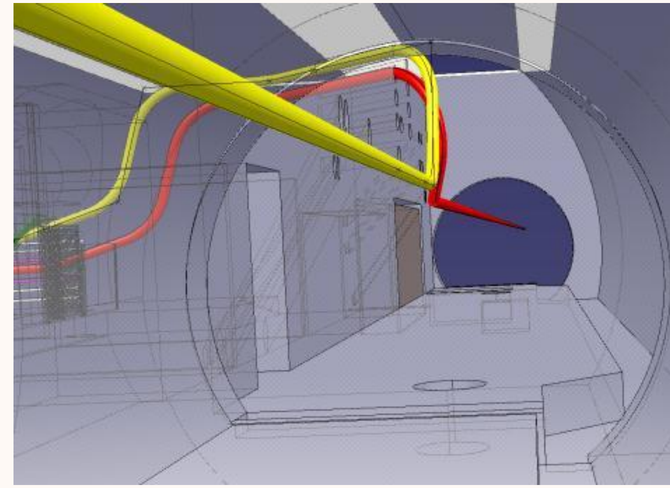
2 Links, Each ~ 500 m long

50 Cables per link rated at 600 A

|Itot| = 30 kA

Removal of LHC cryostats from tunnel

Underground installation



LHC P1 and P5

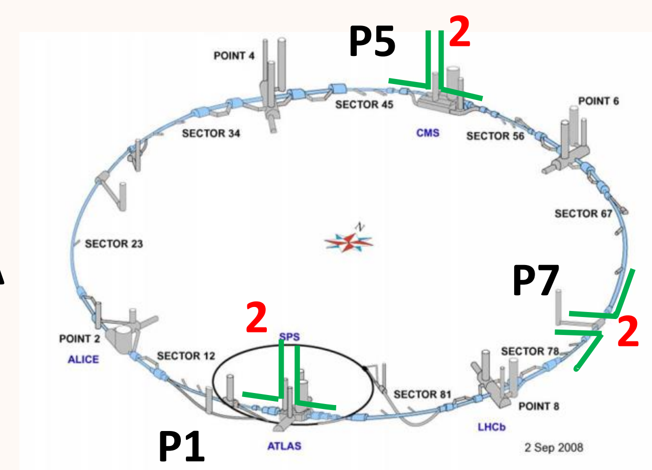
2+2 Links, Each ~ 300 m long

42 Cables per link rated at up to 20 kA

|Itot| = 150 kA

Upgrade of Hi-Luminosity Triplets

Surface Installation



Superconducting Links Characteristics

LHC P1 and P5

2+2 Links, Each ~ 300 m long

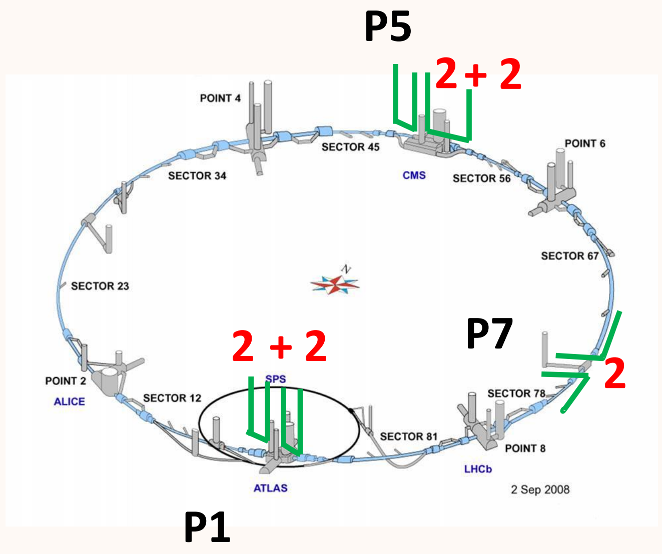
63 Cables per link rated at up to 6 kA

|Itot| = 200 kA

Removal of LHC cryostats from tunnel

Feeding of Arc and MSs magnets

Surface Installation



In total: 10 SC Links
Multi-circuit assemblies
feeding different magnet circuits

Total length of superconductor required > 1000 km (7 tons)

High Temperature Superconductors

Conductors available:

Nb-Ti wire. Operation at liquid He temperature. Limited temperature margin

Bi-2223, Y-123 tape. Operation at up to liquid nitrogen temperature

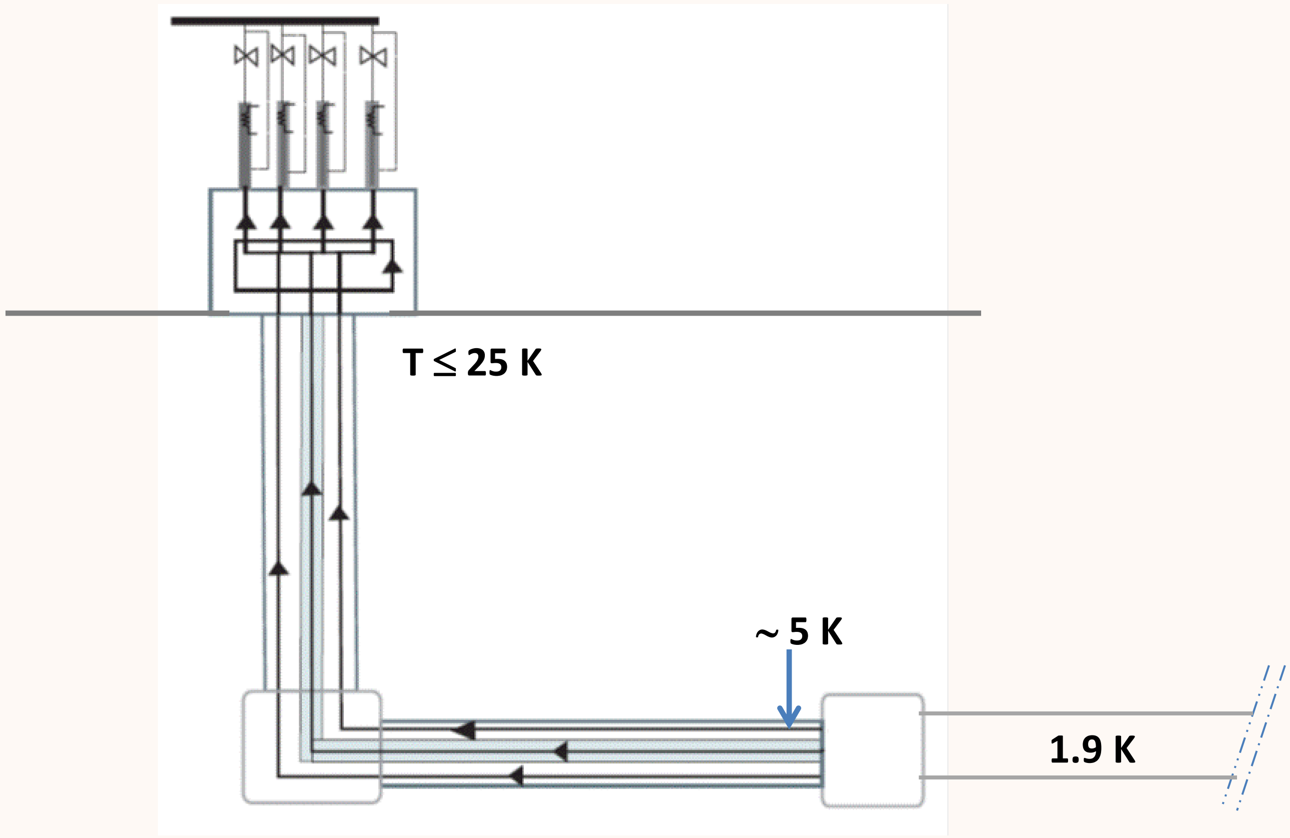
MgB_2 available in the form of tape (Columbus Superconductors). Operation at up ~ 25 K- 30 K

MgB_2 **round wire** being developed in collaboration between CERN and Columbus Superconductors

Operating Temperature

Surface

Tunnel



Maximum operating temperature of the cable = 25 K

He gas cooling

Operation in self-field (B <1 T)

Conductor Specification

Ic(20 K, 0.5 T)	> 500	A
Ic(25 K, 0.5 T)	> 400	A
Ic (30 K, 0.06 T)	> 300	A
Jc,eng(20 K, 0.5 T)	> 630	A/mm^2
Jc,eng(25 K, 0.5 T)	> 500	A/mm^2
Jc,eng(30 K, 0.06 T)	> 380	A/mm^2
n-value (25 K, 0.5 T)	> 30	
Φ of strand **Width of tape**	< 1 4	mm mm
Copper stabilizer	≥ 12	%
RRR Copper stabilizer*	> 80	
Bending radius*	< 100	mm
Critical tensile strain (RT)*	> 0.3	%
Unit length	1000	m

Properties of reacted conductor

Cables Specification and Development

Low-current rating (P7)

600 A @ 25 K, B < 100 mT

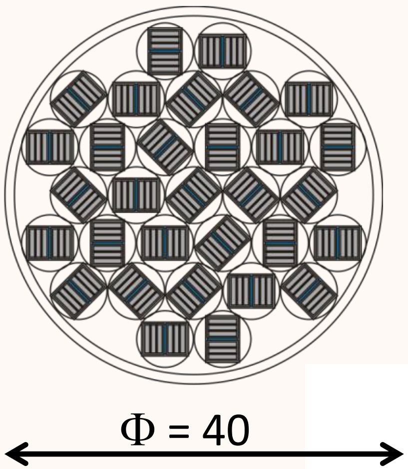
High-current rating (P1 and P5)

20000 A, 6000 A, 3000 A @ 25 K, B < 1 T

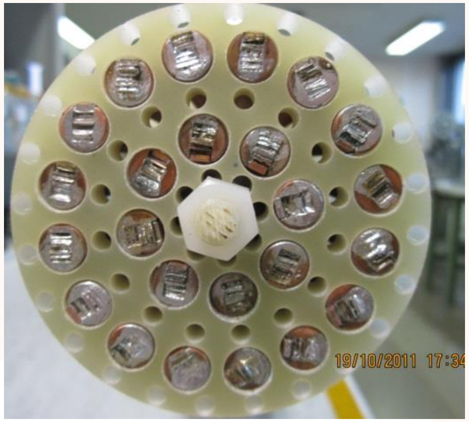
Twisted-Pair Cables

Use of tape for 600 A circuits

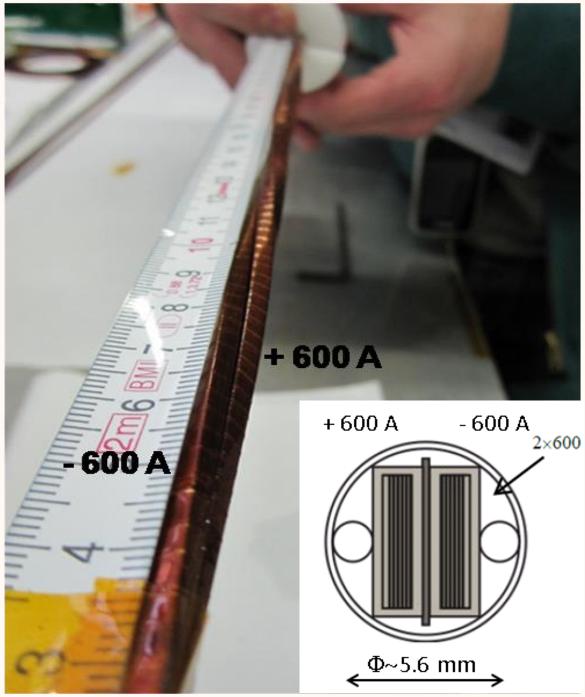
MgB_2, YBCO, BSCCO 2223



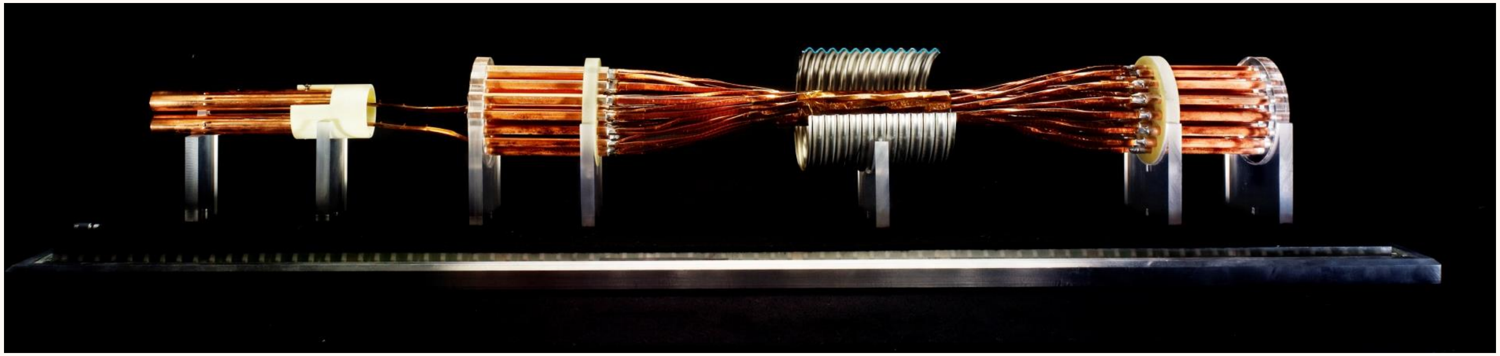
Terminations



Twisted-Pair Cable

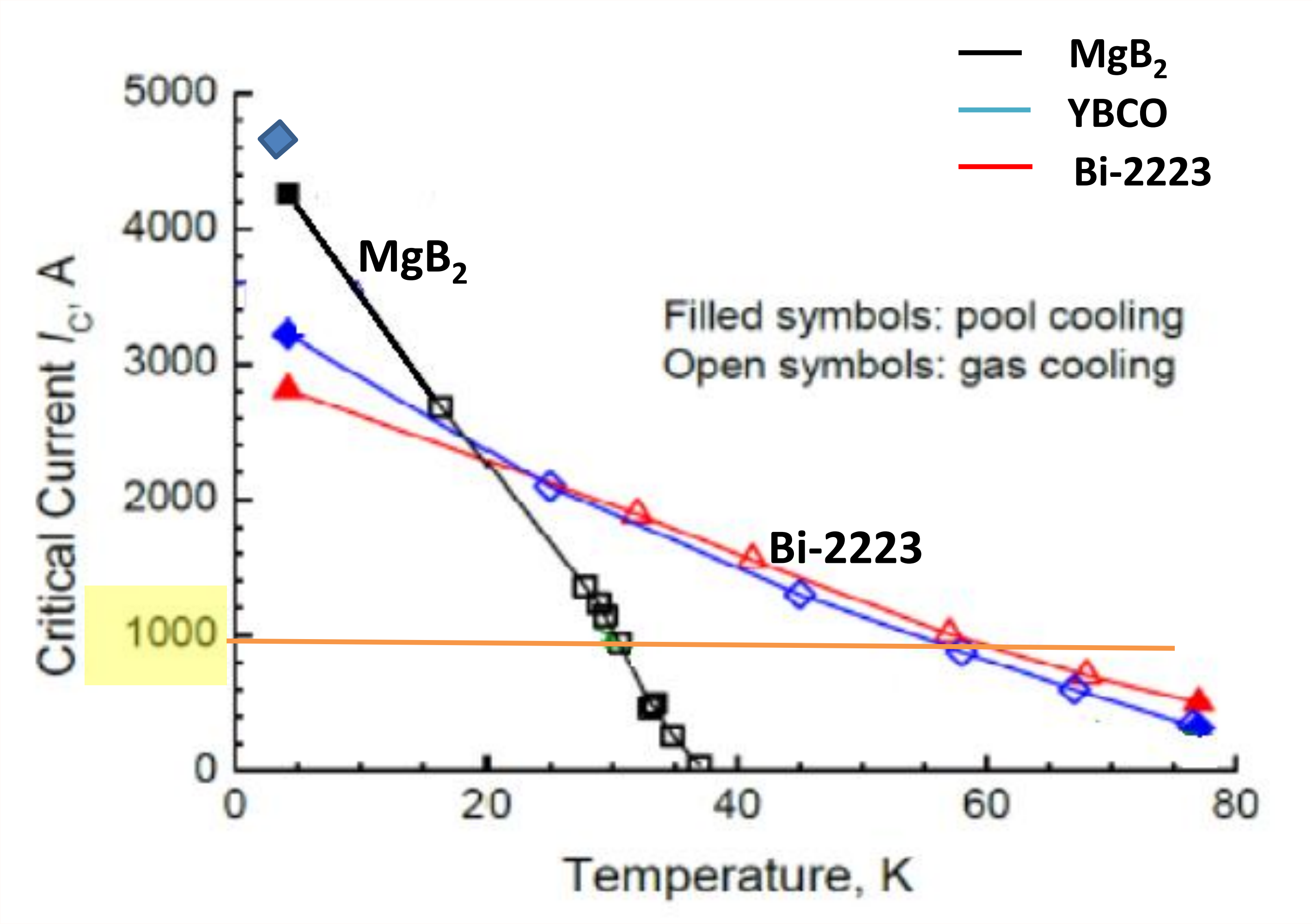


Mock-up of 25 Twisted-Pair Cables

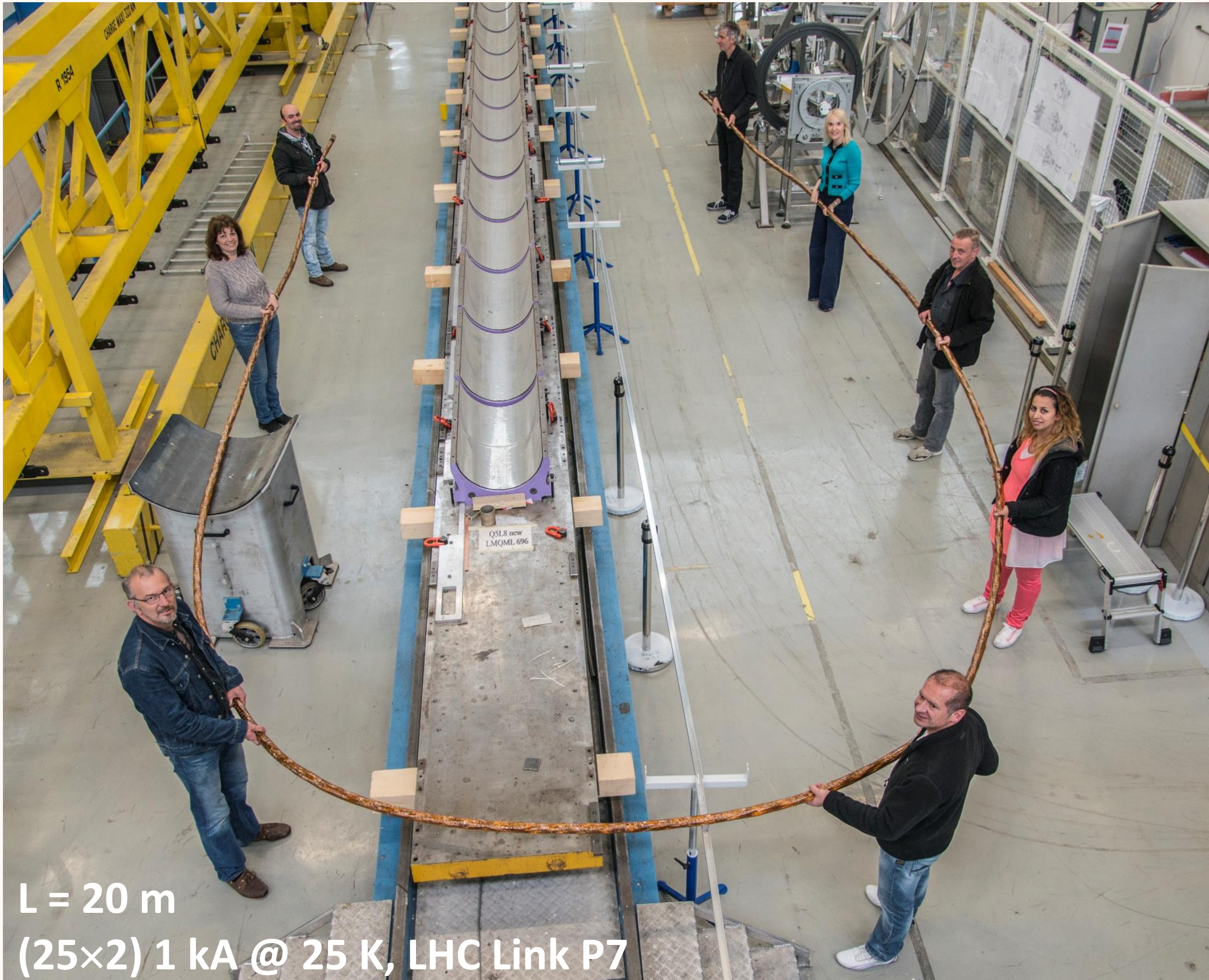


Twisted-Pair Cables

Ic >2.5 kA @ 20 K – self-field



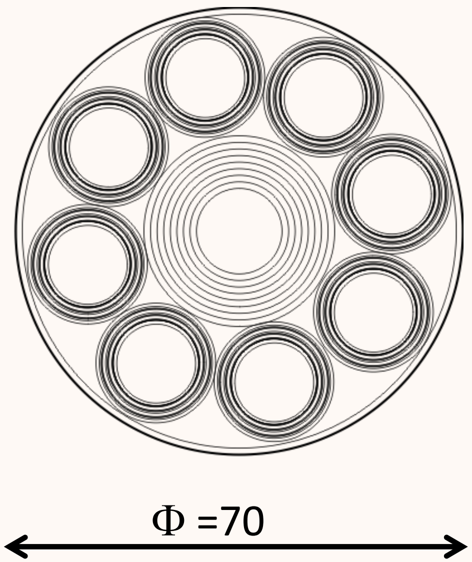
Measurements in He gas at the University of Southampton, Y. Yang, C. Beduz et al.



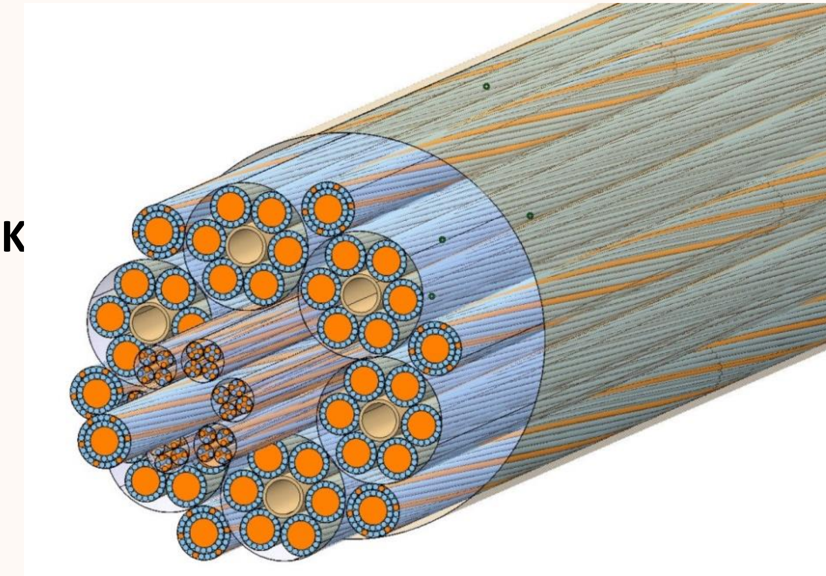
L = 20 m

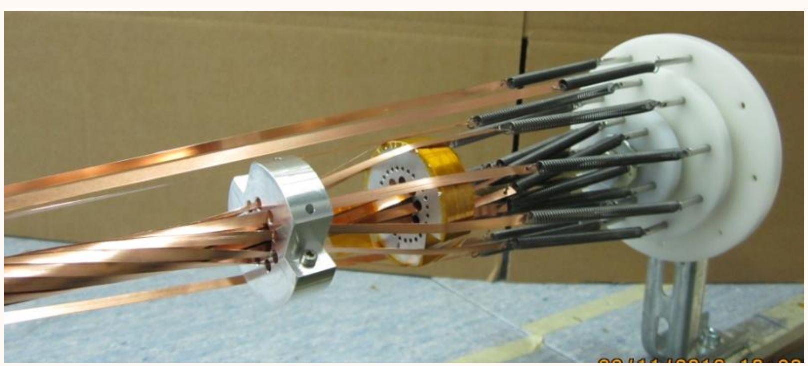
(25×2) 1 kA @ 25 K, LHC Link P7

High-Current Rating, LHC P1 and P5

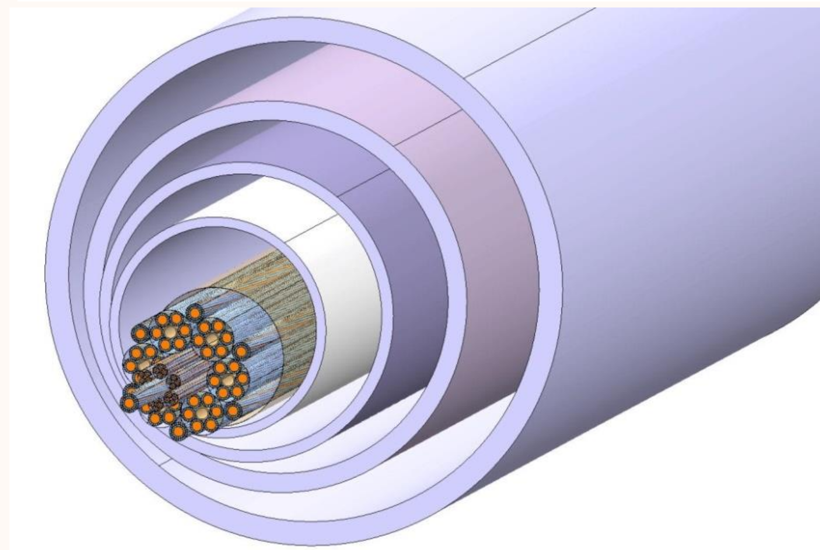


24 × 6000 A
42 × 600 A
Itot = **169 kA & 20 K**
(~ 2 × 84.5 kA)





Tape Conductor

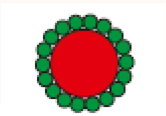


Wire Conductor

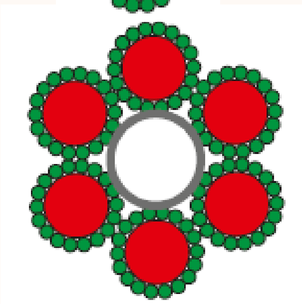
High-Current Rating, LHC P1 and P5

Cu

MgB_2 , Φ = 0.85 mm



18 MgB_2 wires
Φ = 6.5 mm

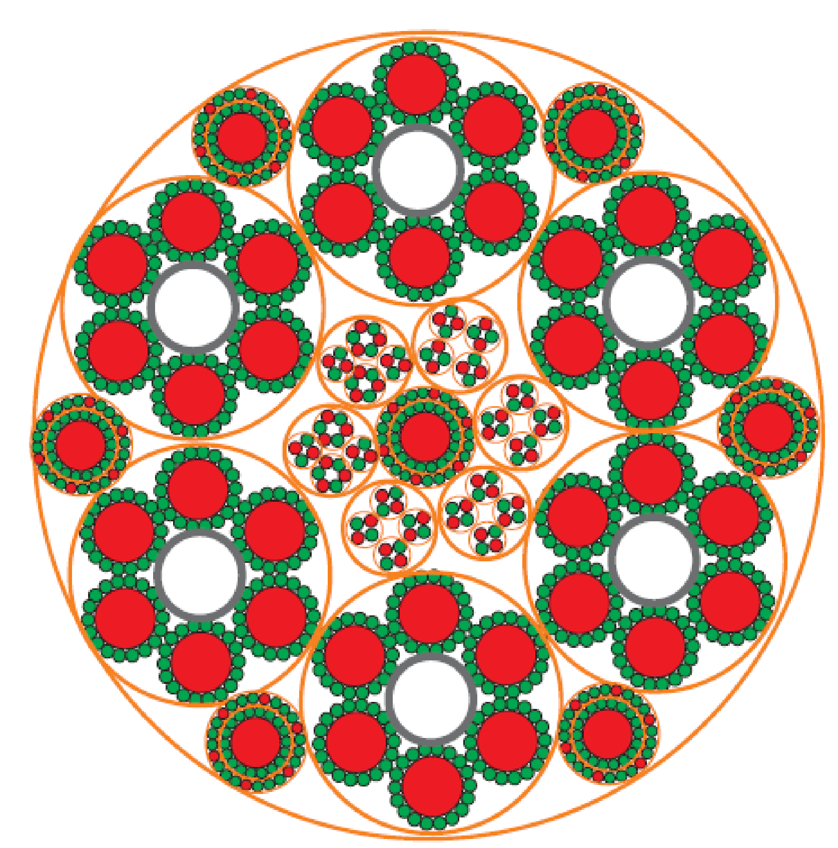


20 kA
Six cables, Φ = 19.5 mm

Concentric ± 3 kA
Seven cables, Φ = 8.4 mm

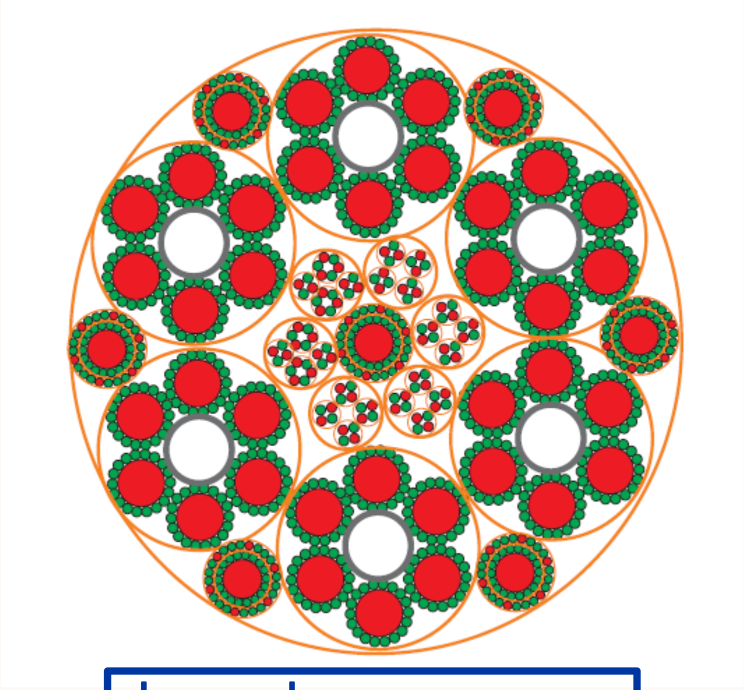
0.4 kA
Four cables

0.12 kA
Eighteen cables



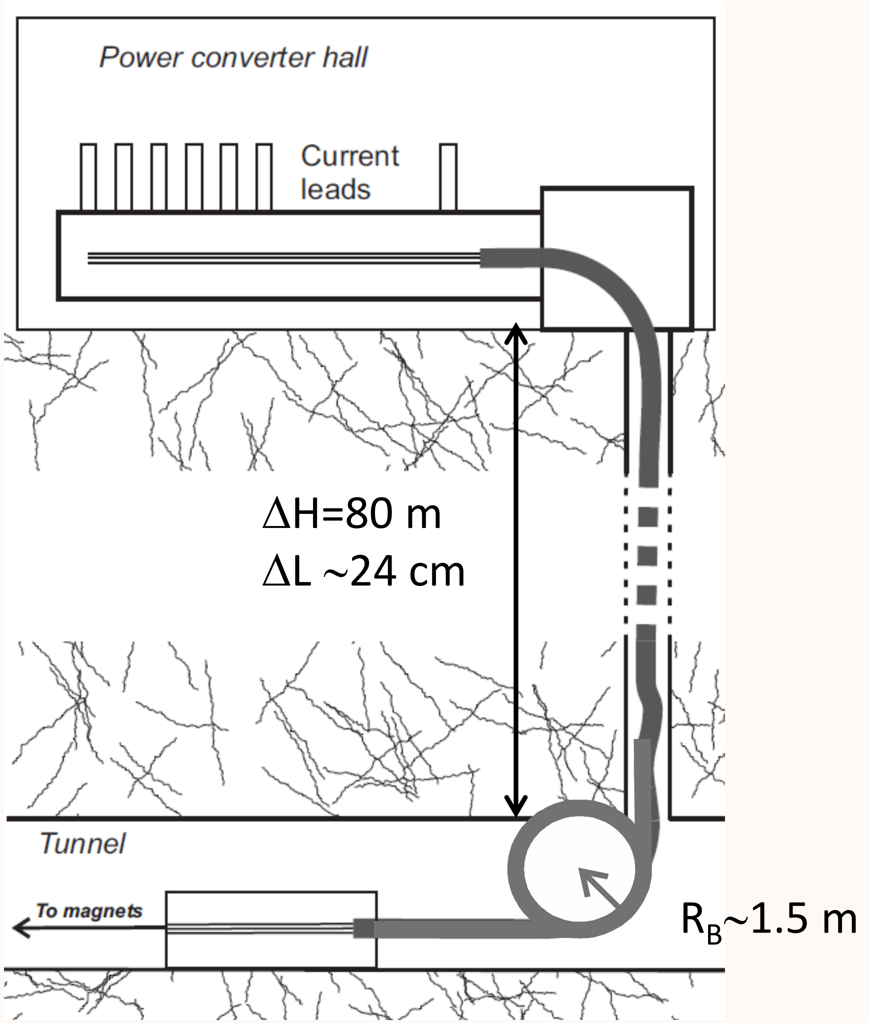
Φext ~ 65 mm

Cable for Hi-Luminosity Magnets LHC P1 and P5



|Itot| = 150 kA

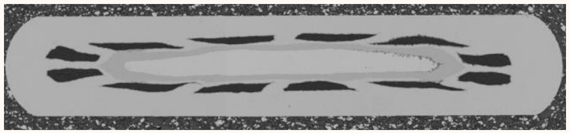
Mass ~ 11 kg/m
(880 kg for ΔH=80 m)



Semi-flexible cryostat external diameter = 220 mm

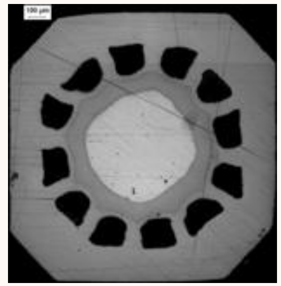
MgB_2 Conductor Development (1/4)

3.6×0.67 mm^2



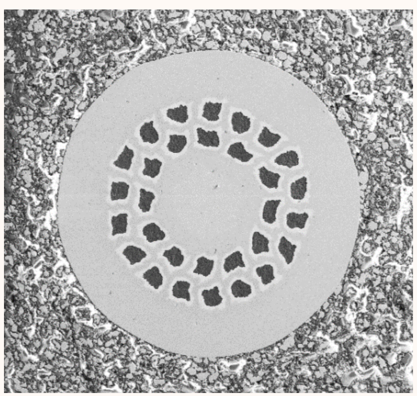
1.6×1.6 mm^2

1.1×1.1 mm^2

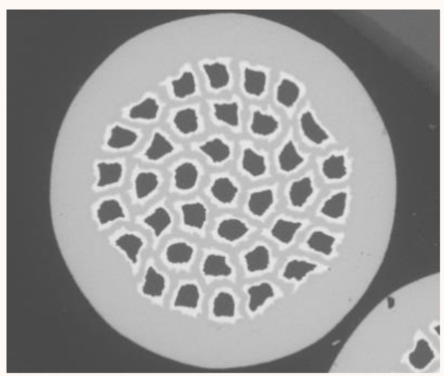


Ni Matrix
12 MgB_2 filaments
Cu core – Fe barrier
Filling factor ~ 14 %

Φ = 0.98 mm



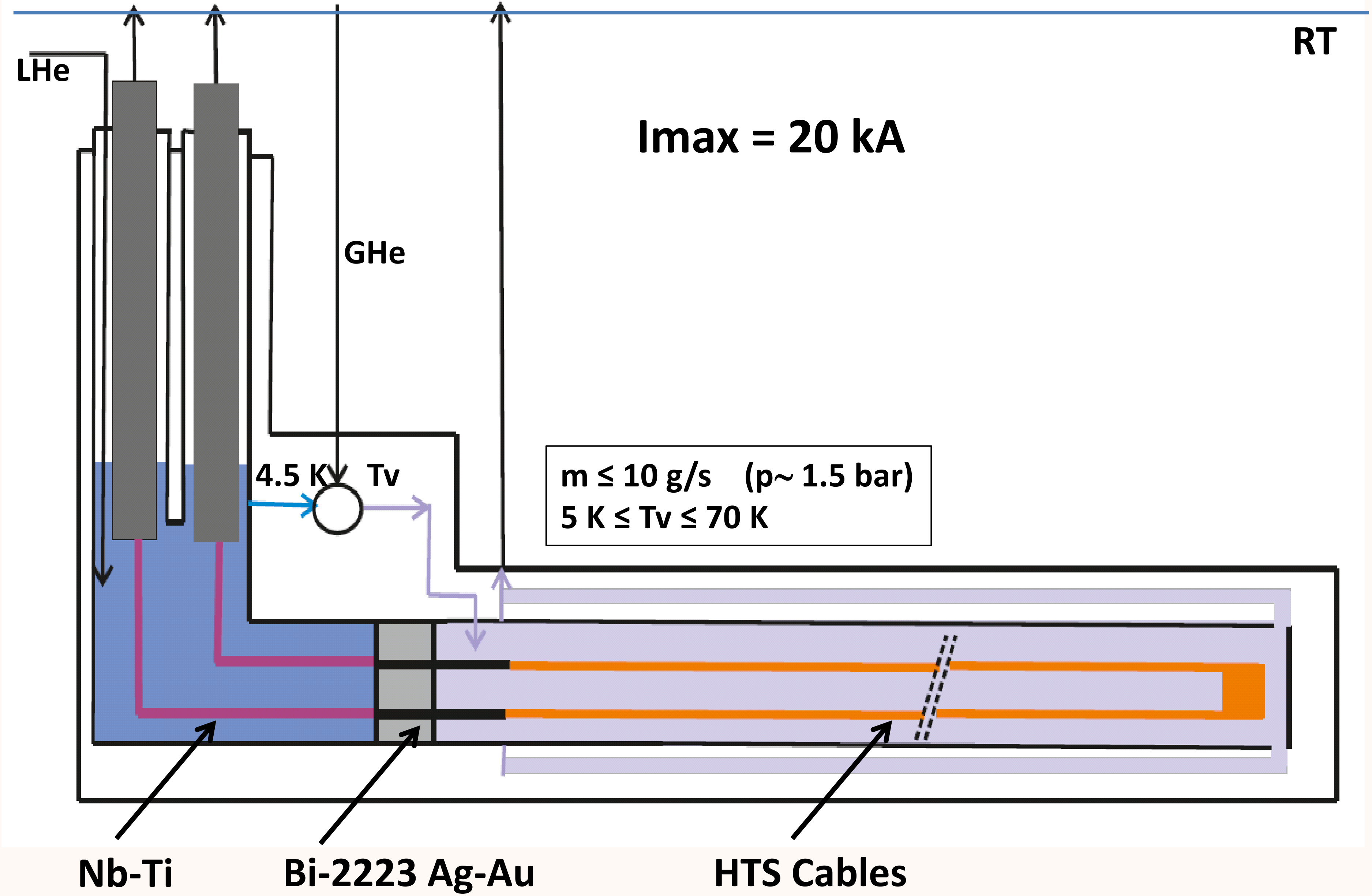
Φ = 0.85 mm



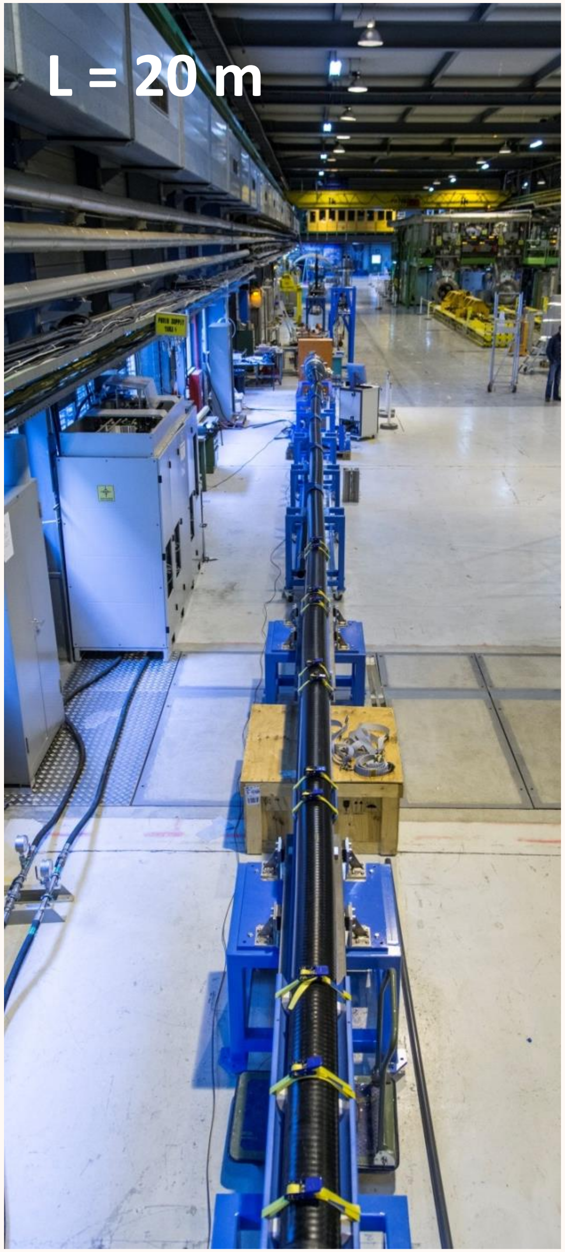
Monel Matrix
30/37 MgB_2 filaments
Nb + Ni barrier
Filling factor up to ~ 18 %

Wire produced at Columbus Superconductors for the Superconducting Link Project

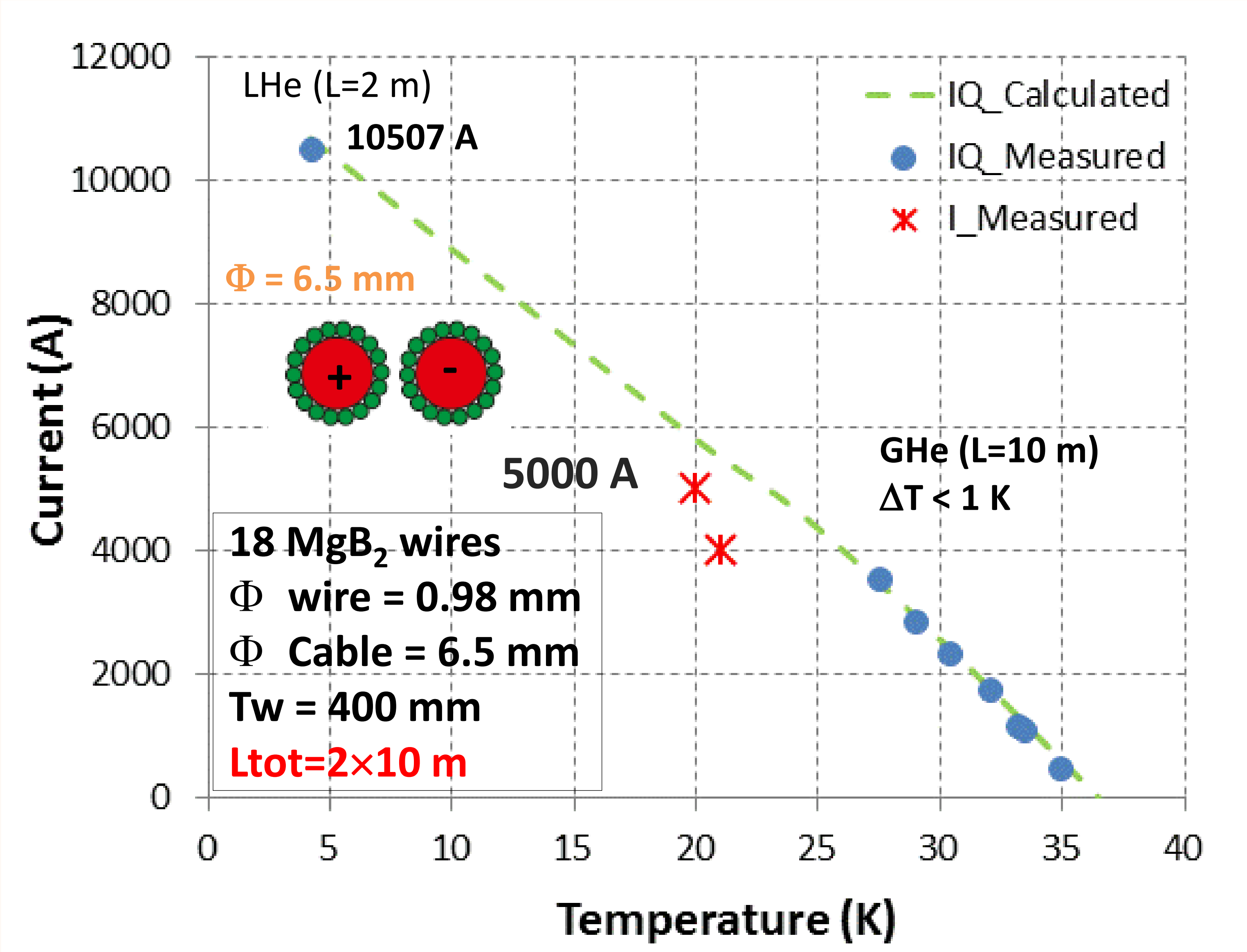
Superconducting Link Test Station at CERN



Superconducting Link Test Station at CERN



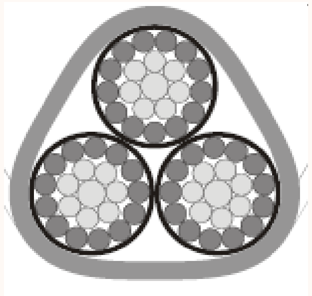
Measurement in GHe of 10 m long cables



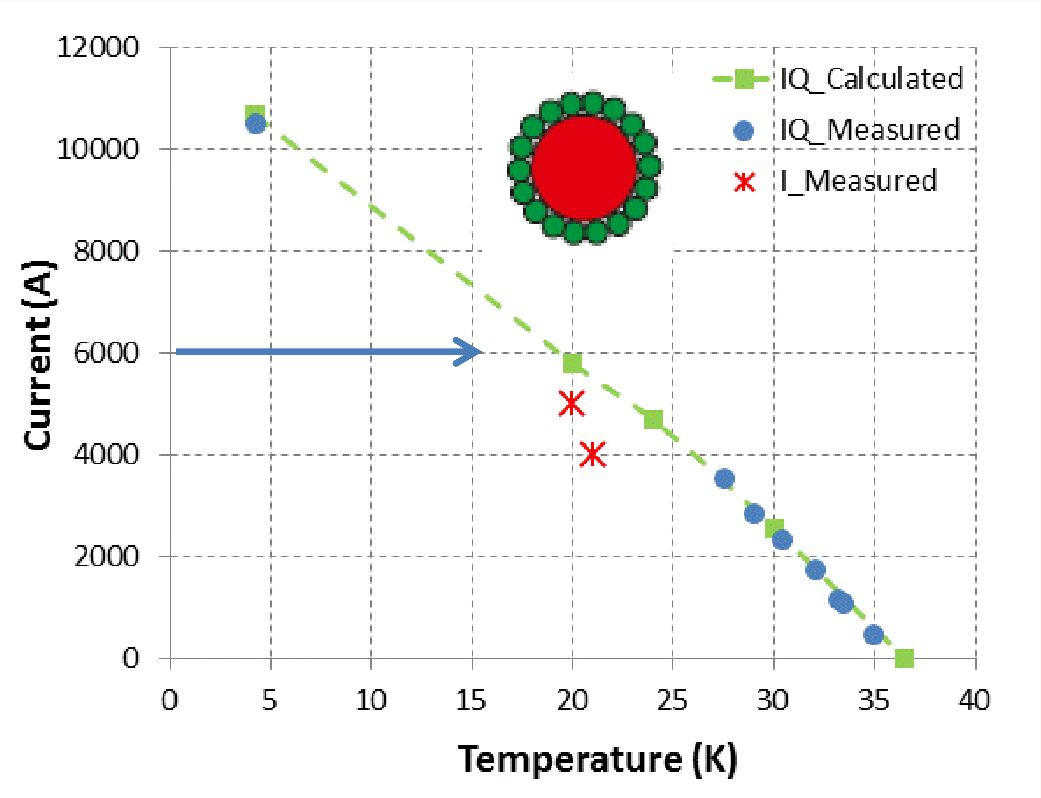
Nb-Ti vs MgB_2 for bus-bars

LHC Nb-Ti cable
6 kA
Operated at T<6 K

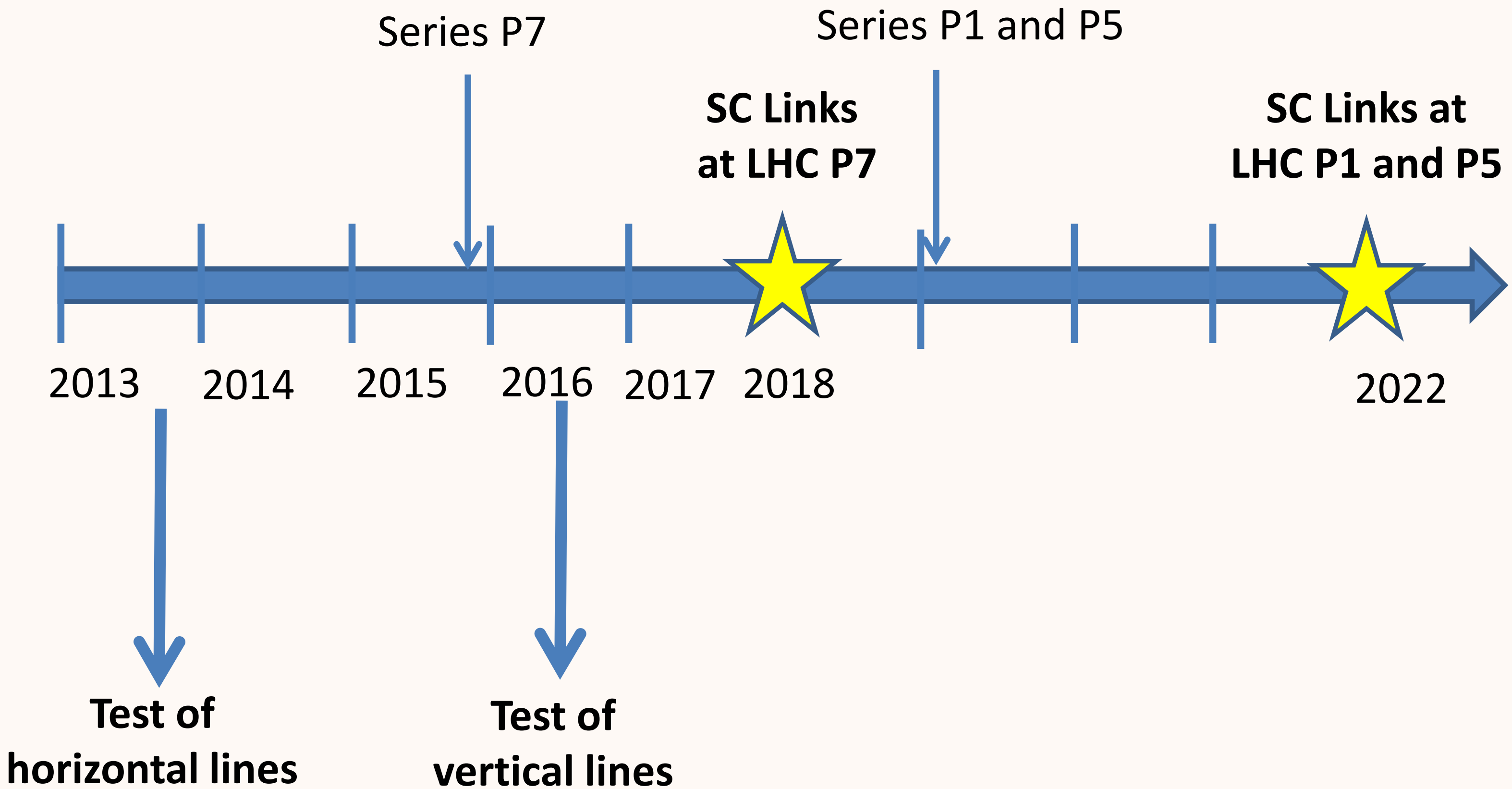
SC Link MgB_2 cable
6 kA
Operated at T< 20 K



3×6 kA



Timeline


Series P7
Series P1 and P5
SC Links
at LHC P7
SC Links at
LHC P1 and P5
2013
2014
2015
2016
2017
2018
2022
Test of
horizontal lines
Test of
vertical lines

- **Energy saving in a superconducting system: electrical transfer**

- **Superconducting Links for the LHC: project overview**
  - Motivations, application to the LHC Upgrades
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- **Conclusions**

Transfer of 20000 A

Aluminium at Room Temperature*

Water cooling – 5 m^3/h

P=880 W/m

A_cond= 9090 mm^2

W = 24.5 kg/m – 2.45 tons

Φext = 120 mm

L=100 m

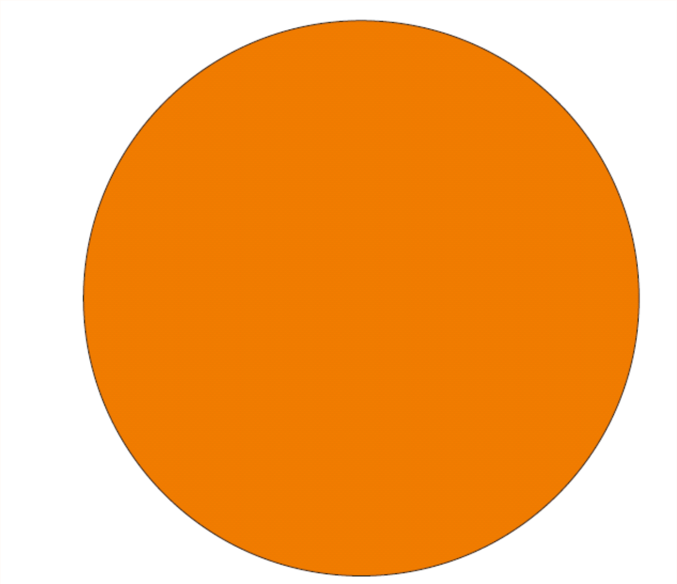
MgB_2 with copper stabilizer

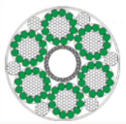
He gas cooling, Tmax=25 K

A_cond~ 100 mm^2

W ~ 1 kg/m – 100 kg

Φext=18 mm

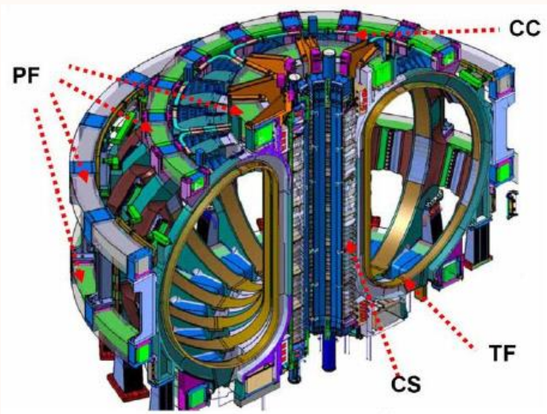


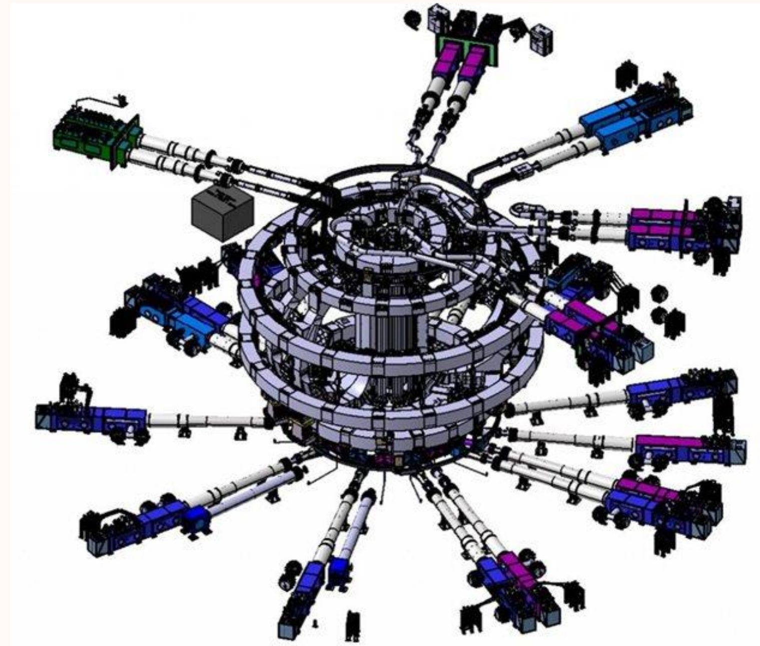


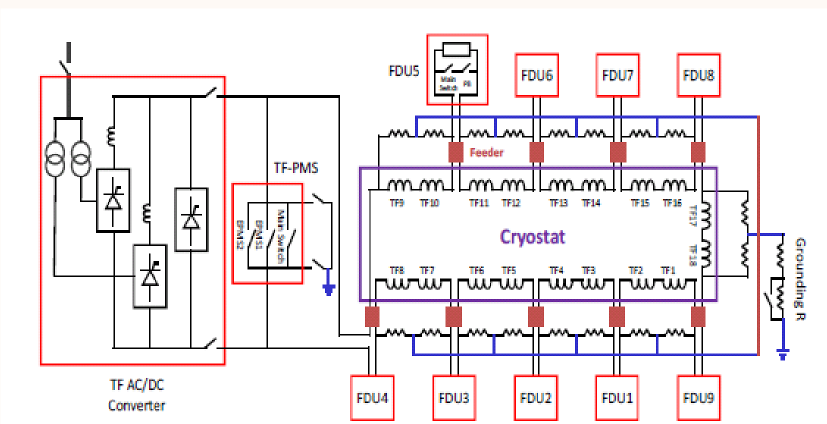
*$\rho_{Al}(RT) = 2 \cdot 10^{-8}\,\Omega$ m

Replacement of High-Current resistive bus-bar with SC lines

Ex. ITER TF Coils





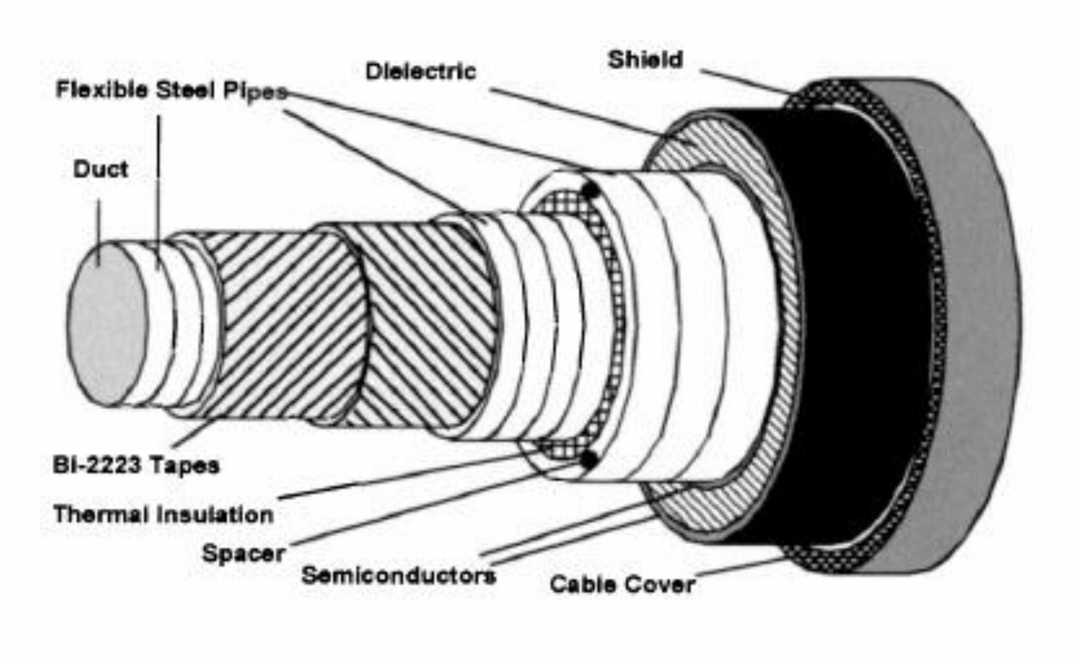


9 × 68 kA DC Circuits (18 Toroidal Field Coils)

ITER bus-bar

EFDA study*: design of the **same type as that being developed for power transmission systems based on HTS tape conductor**

Φ = 152 mm - to be compared with **225×225 mm²** of the Al water cooled TF coils bus bar (68 kA)



*R. Wesche, R. Heller, W.H. Fietz, V.L. Tanna, G. Zahn, EFDA Ref. TW4-TMSF-HTSCOM, 2005

ITER bus-bar

Study commissioned by EFDA* of an alternative to Al bus-bar based on the use of **HTS – BSCCO 2223 Tape (**65 K)

This was found to **be attractive regarding space and weight**

BUT

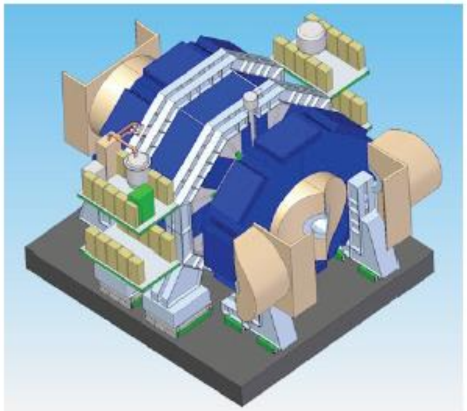
Too expensive – even taking into account the power saving over 20 years of operation

MgB_2 High-Current Cables of the type being developed for LHC would be a viable option

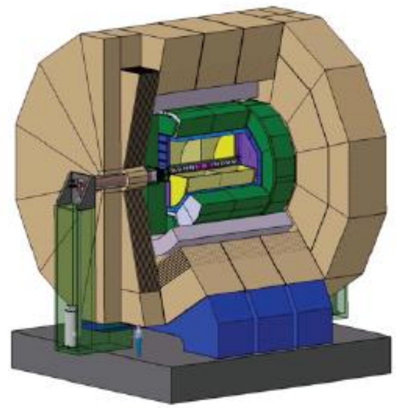
*R. Wesche, R. Heller, W.H. Fietz, V.L. Tanna, G. Zahn, EFDA Ref. TW4-TMSF-HTSCOM, 2005

SC Links for "pull-push" experiments

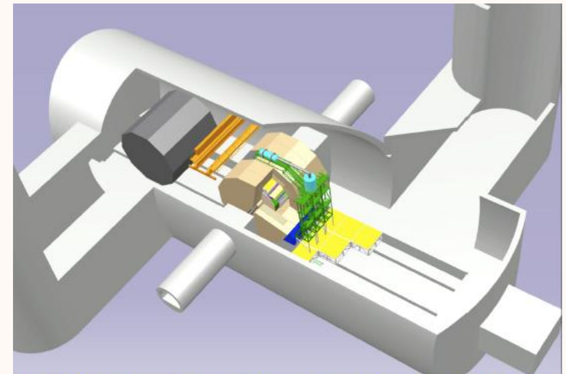
In **CLIC/ILC** it is foreseen to install **2 experiments** that share the single interaction point on a **"push-pull"** basis



SiD with Platform



ILD with Platform



The ILD detector will be placed on a concrete platform to avoid possible damages due to non-synchronised movements or from vibrations during push-pull and also to ease internal alignment challenges. (ILD-LOI)

-det-1 BPL running	2 weeks + 1 week contingency for machine study and inefficiency
-push-pull+calib	1 week
-det-2 BPL running	2 weeks + 1 week contingency for machine study and inefficiency
-push-pull+calib	1 week

Proposed running schedule (ILC) based on an 8-week cycle

It would be an advantage to keep cryogenics and busbars connected for such frequent movement . This could be achieved using semi-flexible cryostats containing MgB_2 based lines of the type being developed for LHC

Conclusions

- Superconducting Links: short-term application of superconducting electrical transfer lines for the feeding of the LHC magnets

- R&D Development is well advanced. Feasibility of making high-current MgB_2 cables using round wires was proven. On-going cables and system development and test aim at fully validate the technology of high-current (150 kA) transfer lines

- Validation of this technology will very possibly lead to applications other than for the LHC accelerator

Thanks for your attention !

Acknowledgements

The work on the SL Link could not have been/be performed without:

the very intense activity within the CERN **SCD section**:

B. Bordini, S. Giannelli, J. Fleiter
G. Hurte, A. Jacquemod, A. Gharib

the collaboration with the CERN cryo-team**: U. Wagner**
and the SM-18 team **:J. Feuvrier**, **Ch. Giloux**

the collaboration with:
the **IASS, Institute for Advanced Sustainability Studies**, Potsdam
Columbus Superconductors, Genova
the **University of Southampton**, Southampton

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